'full-blast' operation of tv sweep tubes in linear service

Although TV sweep tubes are used extensively as linear power amplifiers in amateur equipment, there has been little published data on their use at rf. Here, W6SAI and W6UOV discuss the intermodulation-distortion characteristics of these tubes.

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During the past few years, it has become popular to use TV-type deflection-amplifier tubes as linear amplifiers in amateur sideband gear. These rugged, low-cost pentodes and tetrodes provide amazing PEP capability along with reasonable tube life. However, limited operating information is available on the use of the "sweep tube" in amateur service. Most available data is based upon **heuristic** (trial-and-error) experiments. It is the purpose of this article to provide some meaningful data covering the use of TV sweep tubes in linear service and to examine the intermodulation distortion characteristics of some of them.

Modern horizontal deflection amplifier tubes, while not originally designed for rf work, have several attractive characteristics. There are power-supply economies because they are capable of high peak currents at low plate voltages. Further, wide-spread use in TV sets contributes to low cost and general availability.

Sweep tubes can be divided into two general categories, those designed for black and white television, with plate-dissipation ratings from about 17 to 20 watts, and larger 25- to 35-watt tubes designed for color applications. To satisfy specific design requirements, variations occur in electrical characteristics, internal connections and basing.

the linear amplifier

Modern ssb transmitters generate intelligence at a low level; it is increased to the operating level by means of one or more linear-amplifier stages. The linear amplifier is a device with an output envelope amplitude which is directly proportional to the input envelope amplitude. In other words, the linear amplifier has constant gain, independent of signal amplitude up to the point of overload. The perfect linear amplifier, of course, does not exist; to a greater or lesser extent all linears exhibit amplitude distortion and gain variations with changes in signal level.

A previous article[1] discussed envelope or **intermodulation distortion** (IMD) tests run on high-power linear-amplifier tubes and how the tests were made. Carrying this investigation a step further, we have made intermodulation-distortion measurements on various small TV-type tetrode and pentode tubes, particularly under "full-blast" operation commonly used in amateur-type ssb exciters and driver stages. The results of these tests are discussed and tabulated in this article.

intermodulation distortion

Intermodulation distortion is a particularly noxious form of amplitude distortion found in linear amplifiers driven by a complex signal having more than one frequency. Speech, for example, consists of a multiplicity of tones and is susceptible to IMD in a nonlinear system. Intermodulation distortion of course exists to a degree in all ssb amplifiers. The overall excellence of a linear amplifier may be expressed in terms of the level of intermodulation products as compared to that of the output signal.* The distortion products consist of spurious signals, some of which fall close to, and sometimes within, the operational passband of the amplifier. These spurious signals cannot be removed from the signal by the simple tuned circuits of the equipment. These unwanted emissions are called **odd-order products.**

A clean ssb signal generated by a well-designed and intelligently-operated transmitter occupies little more spectrum than the passband of the intelligence. On the other hand, a poorly-designed or badly-adjusted ssb transmitter with high-level odd-order distortion products (splatter) can smear a swath of frequencies many times wider than that required for transmission of intelligence.

The amount of intermodulation distortion a given signal may possess without creating intolerable interference in an adjacent channel or degrading the transmitted intelligence is subjective and debatable. Some forms of transmission, such as multiplex, require extremely low IMD to faithfully preserve the complex intelligence transmitted.

When the intelligence bandwidth is somewhat less, as is the case with voice, a higher level of IMD may be acceptable. This depends upon the degree of fidelity required, the masking-channel noise level, and the degree of interference tolerated in adjacent channels. Severe intermodulation distortion of a voice signal is characterized by "gravelly" audio and excessive adjacent channel splatter.

As an example, a 1000-watt (PEP output) ssb transmitter with an IMD level of —40 dB in a two-tone test will produce 0.1 watt of power in each of the third-order products. A 1000-watt transmitter, on the other hand, having an IMD level of —20 dB in third-order products will have 10 watts power in the third-order products falling outside the intelligence passband. While 0.1 watt may seem miniscule, 10 watts of unwanted signal may be intolerable, especially when it falls on top of that S-3 DX signal you are listening to!

Studies are presently underway to formalize distortion testing techniques for linear amplifiers. Criteria will be established so linear systems may be evaluated in respect to

* For convenience, the ratio between one of the test signals and one of the IMD products is read as a power ratio expressed in dB below the test signal. Other methods of expression can make the IMD products seem as much as 6 dB better than they actually are.

table 1. 6146/6146B, class-AB$_1$ service.

test #	dc plate voltage	dc grid voltage (1)	dc screen voltage	zero signal dc plate current (mA)	maximum signal dc plate current (mA)	maximum signal dc screen current (mA)	resonant load impedance (ohms)	plate input power (watts)	plate output power (watts) (2)	third-order IMD products (dB)	approximate plate dissipation (watts)
1	600	—46	200	25	103	9	3570	61	41	—25	16 (CCS)
2	750	—51	200	25	118	7	2825	88	55	—22	28 (ICAS)
3	800	—69	290	30	125	10	3620	100	59	—24	35 (4)
4	800	—77	290	25	180	13	2300	145	91	—19	45 (3)

1. Adjust grid bias for stated zero-signal dc plate current.
2. Does not include tank-circuit losses (about 10%).
3. Applies only to 6146B.
4. Data taken from Collins S-line. Measurements made without rf feedback.
5. Maximum plate and screen currents are listed as single-tone values; voice peaks will run 1/3 to 1/2 this value.

distortion levels acceptable for various transmission circuits. In the meantime, distortion levels are set primarily by the limitations imposed by the state-of-the-art.

The present state-of-the-art in commercial and military ssb equipment calls for third-order IMD products with power levels better than - 40 to - 60 decibels below one tone of a two-tone test signal. The latter degree of linearity may be achieved by proper choice of low-distortion tubes operated in conjunction with rf feedback circuitry. Amateur requirements, as we shall see, are less restrictive by several degrees of magnitude. With an optimum choice of tubes and operating voltages, plus the addition of feedback equipment, designers and users obtain IMD levels (without expensive test equipment) which are acceptable in today's amateur gear.

intermodulation measurements

One industry-wide technique of measuring the intermodulation distortion characteristics of a vacuum tube operating in a linear mode is to run the tube in a two-tone rf test under laboratory conditions where all the parameters are controlled and observed. Various IMD products may be noted on a panoramic analyzer or tunable voltmeter. The circuit parameters and electrode voltages of the tube under test are changed at will to facilitate a search for a condition of low IMD distortion. A typical IMD presentation on the screen of the analyzer is shown in **fig. 1.**

Power tubes up to the 100-kilowatt level or so have been examined in this fashion; a considerable body of literature and test data exist on the linear characteristics of large ceramic and "hard glass" tubes with plate-dissipation ratings of 250 watts and higher. Little data, however, has been formally accumulated on the linearity characteristics of low-power driver tubes. These tubes are usually "soft-glass"** tetrodes and pentodes that are versions of inexpensive audio or television sweep tubes.

In present design practice, high-power amateur ssb gear is physically divided at the 100- to 200-watt PEP level into an exciter and a high-power linear amplifier. The majority of exciters, moreover, use one or more receiving-type tubes of the 6L6 or 6146 family or TV sweep tubes as a linear amplifier.

the 6146 family of tetrodes

The 6146 family of tetrodes is a descendant of the 1936 "grand-daddy" 6L6 beam tetrode. Of convenience to the radio amateur and engineer is the fact that the 6146 family is rated for rf service. Also, application data covering various modes of rf operation are readily available. This popular family of small tetrodes is characterized by short, low-inductance structures which perform well in proper circuitry up to 150 MHz or so.

** Soft glass refers to lead-silicate glass which normally limits the envelope temperature to 240° C or less. Hard glass (Nonex for example) permits envelope temperatures over 300° C.

table 2. ICAS sweep-tube ratings, class-AB_1 service.

test #	tube type	dc plate voltage	dc grid voltage (1)	dc screen voltage	zero signal dc plate current (mA)	maximum signal dc plate current (mA)	maximum signal dc screen current (mA)	resonant load impedance (ohms)	plate input power (watts)	plate output power (2) (watts)	approximate plate dissipation (watts) signal
1	6GJ5	500	—43	200	30	85	4	3000	42.5	17.5	22
2	6HF5	500	—46	140	40	133	5	1900	66.5	28.8	35
3	6JB6	500	—42	200	30	85	4	3000	42.5	17.5	22
4	6JE6	500	—44	125	40	110	4	2300	55.0	23.4	30
5	6JG6	450	—35	150	30	98	5	2200	44.0	18.9	21
6	6JM6	500	—42	200	30	85	5	3000	42.5	18.3	22

1. Adjust grid bias for stated zero-signal dc plate current.
2. Does not include tank-circuit losses (about 10%).
3. Maximum plate and screen currents listed are single-tone values; voice peaks will run 1/3 to 1/2 this value.

A series of intermodulation distortion tests*** run on the 6146/6146B show that this tube exhibits an intermodulation distortion figure in the area of —22 to —25dB for third order products when operated within its published specifications (**table 1**). When external rf feedback is used (such as employed in the Collins S-line), equipment using the 6146/6146B achieve IMD levels of —30 dB or better (test #3).

Attempts to drive the 6146 beyond its maximum power capability, of course, represents a simple exchange of tube life and substantially higher distortion levels for more output power (test #4).

The peak ICAS plate current capability of the 6146B in class AB_1 intermittent service is limited to about 125 mA dc. At a reasonable plate potential (750 volts or so), the PEP input level runs about 94 watts. At an efficiency of 65%, plate dissipation is on the order of 34 watts or so, just within the upper rating of the tube.

sweep tubes

Several generations of high-transconductance beam-forming tetrodes and pentodes of 15- to 30-watts plate dissipation have been created for use in TV-deflection circuits. Examples of this family are the 6DQ5, 6HF5, 6JE6, 6GB5 and others. All of these husky low-cost tubes are descendants of granddaddy 6L6, having more cathode emission, greater gain and higher transconductance than their worthy ancestor.

Generally speaking, these sweep tubes are very nearly identical in overall electrical characteristics, varying mainly in physical configuration, pin connections and power capacity. A study of some of these tubes shows that in many cases the various internal parts of the tubes (plates, grids, cathode and supporting structure) are virtually identical. Perhaps the variations in ratings are determined by the applied pulse voltage and sweep parameters of the TV receiver in which the tube is to be used. In all cases, maximum capability of the tube is limited by glass-envelope temperature; 240° Centigrade or less.

Most of the common TV sweep tubes used in radio amateur ssb linear-amplifier service are not rated for this use by the manufacturer. Furthermore, not all of them are rated for audio service, from which ssb ratings may be derived. Class-AB_1 and class-C operating data for some TV sweep tubes is given in "Sylvania News"[2] (see **table 2**). According to the author, W. D. Murphy, maximum plate dissipation for some sweep tubes in intermittent ssb linear amplifier service is estimated to be about 1.25 times that value given for TV service.

Several years experience with sweep tubes in linear amplifier service by various manufacturers of amateur gear proved Murphy's data was conservative. In fact, TV sweep tubes may be deliberately subjected to high

*** All tests described in this article were conducted by the authors using the Intermodulation Distortion Analyzer in the Eimac Power Grid Laboratory. All tests were run at 2.0 MHz.
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peak overloads under the proper circumstances without objectionable loss of life when used in intermittent voice operation. A "full-blast" rating for various tubes was derived (mainly by experience) that permitted PEP input levels of 150 to 200 watts to be achieved, still allowing a good balance between power input, tube cost, and tube life.

This power level is based upon the intermittent nature of amateur transmission, plus the high ratio of peak to average power in the human voice. The factors are hard to pinpoint in actual numbers, but a round, vague figure of 6 dB for the peak to average power ratio has been widely used in designing sweep-tube ssb gear for the amateur market.

With a PEP input of 250 watts under these conditions, the average input power is estimated to run about 62.5 watts over a period of time. If we figure that average efficiency runs about 60% or so, average plate dissipation will be about 26 watts. In most instances, the full-blast rating is further restricted by limiting maximum full-power tuneup periods to 30 seconds in each time period of 2 minutes.

While some rather drastic assumptions are made, practice has shown that full-blast ratings are not unrealistic and good tube life may be achieved (a year or so in normal amateur use). This is provided the operator does not "cook" the tubes during tuneup.

Full-blast operation of sweep tubes in this manner may exceed maximum glass temperature for short periods of time and may eventually lead to seal fractures. When this happens, the tubes go "gassy" after a few hundred hours of operation. Such use, while decidedly uneconomical when applied to a twenty-dollar transmitting tube (especially in commercial gear that stresses reliability), may possibly be considered in a different light when applied to an inexpensive sweep tube that probably will be used only a hundred hours or so during the year. It remains to be seen what happens to the intermodulation distortion level of the small tube when it is subjected to such overload conditions.

Acting upon the assumption that it is economically feasible to operate a sweep tube at a full-blast 100- to 250-watt PEP input level, we ran a series of tests on various types of tubes to determine their linearity characteristics under duress. In order to hold glass temperature to reasonable values, in all cases cooling air was passed over the tube envelope. Typical rf ratings for intermittent voice linear service were tested. In some cases, operating parameters were duplicated from amateur equipment using the tube. Other working data were derived in the laboratory.

Interestingly enough, certain models of the sweep tube, such as some versions of the 6HF5, were found to have the internal cathode connection at the top of the element structure rather than at the bottom. This

table 3. Full-blast ratings for sweep-tubes, class AB_1 service.

test #	tube type	dc plate voltage	dc grid voltage (1)	dc screen voltage	zero signal dc plate current (mA)	maximum signal dc plate current (mA)	maximum signal dc screen current (mA)	resonant load impedance (ohms)	plate power input (watts)	plate power output (2) (watts)	third-order IMD products (dB)	approximate plate dissipation (watts)
1	6DQ5	500	—46	150	48	170	17	1800	85	54	—28	27
2	6DQ5	500	—46	150	48	182	13	1625	91	56	—26	29
3	6DQ5	700	—49	150	35	182	11	2210	127	78	—23	41
4	6DQ5	800	—67	180	30	250	13	1710	200	121	—19	70
5	6GB5	600	—41	200	23	192	14	1900	115	80	—18	27
6	6GE5	600	—45	200	30	132	15	2500	79	51	—22	23
7	6GE5	800	—61	250	25	172	18	2750	138	90	—19	39
8	6HF5	800	—45	125	30	197	7	2170	158	100	—21	48
9	6JE6	750	—63	175	27	218	15	1850	163	102	—20	51
10	6KG6	800	—53	160	30	200	5	1000	160	91	—19	60
11	6LQ6	750	—60	175	25	215	9	1850	161	102	—18	49
12	6LQ6	800	—69	200	25	242	13	1850	197	124	—18	60

1. Adjust grid bias for stated zero-signal dc plate current.
2. Does not include tank-circuit losses (about 10%).

extra-long cathode lead provided built-in degeneration that made the tube difficult to drive on 10 meters.

A summary of operating parameters and intermodulation distortion for various sweep tubes is given in **table 3.** It can be seen from this tabulation that the TV sweep-tube family exhibits IMD figures a bit worse than the 6146 group, being relatively constant in the range of – 18 to – 23 dB for third-order products. Correspondingly large values of fifth and higher order intermodulation products were also noted. Reasons for the relatively high level of intermodulation distortion products for this class of tubes are complex, but are probably based upon a combination of low-plate dissipation capability (which restricts zero-signal plate (current) and nonlinear geometry of grid and screen structures.

The degree of intermodulation distortion in the sweep-tube family does not seem to be a direct function of signal level at which the tube is operating as a class-AB_1 amplifier. Reducing the input level of the sweep tube does not cause a corresponding improvement in intermodulation distortion products; the IMD level holds rather constant as power is reduced.

color sweep tubes

Recent demands for heavy-duty sweep circuits in color television receivers have produced some truly heroic tubes capable of delivering unusually large values of cathode current under conditions of low plate and screen voltage. In particular, the 6KG6, 6KD6 and 6LQ6 seem to be well qualified to deliver large amounts of raw rf under a chosen set of operating conditions. Accordingly, these tubes were examined for IMD characteristics in linear-amplifier service. The results of the tests are tabulated in **table 3.**

The 6LQ6 is rated at 30-watts plate dissipation and the 6KG6 is rated at 34-watts dissipation for TV service. Using the Sylvania rule-of-thumb mentioned earlier, an intermittent rating of 38- and 43-watts dissipation may be expected for intermittent service. Based upon experience with black-and-white sweep tubes, it is reasonable to estimate that the larger sweep tubes may withstand full-blast bursts in excess of twice these values in intermittent amateur voice service. The 6LQ6, moreover, has an additional interesting rating of 200-watts temporary plate dissipation for periods of 40 seconds or less. This allows some latitude in the tuneup process when excessive values of plate dissipation are likely to occur.

The power capability of these compact and inexpensive sweep tubes is impressive. While the plate dissipation under single-tone test conditions is grossly exceeded, if cooling air is circulated around the tube, it is reasonable to assume it is within prudent limits under voice modulation.

The 6DQ5 and 6LQ6 tubes provided the highest level of peak plate current, power output and plate efficiency—about 120 watts PEP output at a PEP input level of approximately 200 watts. Third order intermodulation products ran about – 18 or – 19 dB below one tone of a two-tone test signal. The physically smaller 6GB5 also gave good account of itself, providing a power output of about 80 watts PEP.

It can be seen from the chart that the family of sweep tubes provides a continuum of conforming data, much alike in important aspects. In some instances, maximum-signal plate current is limited by screen dissipation, but in all cases plate dissipation vastly exceeds the published maximum values.

It should be noted that these tests were conducted at a frequency of 2 MHz. It has been reported to us from another source that some 6KG6 tubes failed in linear-amplifier service at 14 MHz at a power input of about 250 watts PEP. Examination of the damaged tubes showed that the internal connecting lead from the cathode base pin to the element structure had melted. It was conjectured that this lead may be made of some type of resistance wire to inhibit "snivets" (vhf parasitics sometimes found in sweep-oscillator service). No tube failures were encountered in the 2-MHz intermodulation tests.

Finally, it should be mentioned that the efficiency of the 6KG6 ran somewhat lower than that predicted by examination of the constant-current characteristics of the tube. Conjecture on this point leads to the thought that the inductance or resistance of the in-

table 4. 6550, class-AB_1 service.

test #	dc plate voltage	dc grid voltage (1)	dc screen voltage	zero signal dc plate current (mA)	maximum signal dc plate current (mA)	maximum signal dc screen current (mA)	resonant load impedance (ohms)	plate input power (watts)	plate output power (2) (watts)	third order IMD products (dB)	approximate plate dissipation (watts)
1	680	—39	340	48	140	20	3010	95	67	—32	21
2	800	—33	290	45	127	15	3920	102	70	—30	25

1. Adjust grid bias for stated zero-signal dc plate current.
2. Does not include tank-circuit losses (about 10%).

ternal cathode lead of the 6KG6 inhibits high-frequency operation of this husky sweep tube. This is a good example of the risk you run when you operate tubes or components in a manner not specified by the manufacturer.

The newly announced 6LQ6 deflection-amplifier tube seems a good candidate for full-blast linear operation, especially in view of the intermittent plate dissipation rating of 200 watts for 40 seconds or less. The 6LQ6, while physically less robust than the 6KG6, provides a good account of itself, as shown in the tabulated data (tests #11 and #12).

It must be noted that these mass-produced tubes have a normal production spread in electrical characteristics. When they are used in parallel, they should be hand-selected to obtain two tubes of approximately the same dynamic characteristic. This can be approximated by comparing the zero-signal resting plate current of a number of tubes and choosing a pair whose currents are closely matched under a given set of operating conditions, or by pairing the tubes in a mutual conductance tube checker.

a "linear" linear-amplifier tube

The only beam tetrode found during these tests capable of relatively high PEP output and low intermodulation distortion in linear-amplifier service was the type 6550, usually employed in hi-fi audio service. The 6550 is capable of a power output of about 67 watts in grid-driven, class-AB_1 service with third-order products – 32 dB down from one tone of a two-tone test signal. Operating data is summarized in **table 4.** In comparison with TV sweep tubes, the 6550 suffers from low transconductance and limited peak plate current. In addition, the interelectrode capacitances are quite high when compared to those of a 6146. Nevertheless, the use of this tube is nearly mandatory if the equipment designer tries to approach an IMD figure better than – 30 dB without the use of feedback. With feedback, an IMD figure better than – 40 dB should be realizable.

summary

While the use of TV type sweep tubes as linear amplifiers in amateur ssb exciters and transceivers may be justified on an economic basis, putting a high-power linear amplifier (even one having negligible distortion levels) after such gear is bound to result in an increase in the level of the various distortion products. In many cases, the distortion products add in voltage amplitude; in all cases, the sum of all components of each frequency product in the output represents the overall distortion level.

Signal distortion, at least to the listener, is a highly subjective thing. To date, the use of sweep tubes in amateur equipment, regardless of the relatively high distortion level, may perhaps be justified when equated against power output and tube life on a dollar-and-cents basis. In any event, until a low-power driver tube in the five-dollar price range comes along to deliver 100-watts PEP at a magnitude of improvement of intermodulation distortion, we'll just have to make-do with the tubes at hand!

references

1. William I. Orr, W6SAI, "Intermodulation Distortion in Linear Amplifiers," *QST*, vol. 47, p. 52, September 1963.
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